

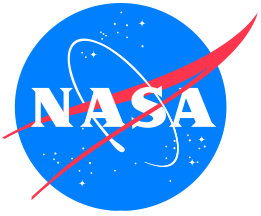
Progress on the Development of Lightweight Dual Frequency/Polarization Microstrip Antenna Arrays on Organic Substrates for Remote Sensing of Precipitation

John Papapolymerou

Assistant Professor

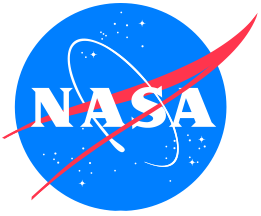
School of Electrical and Computer Engineering

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People:

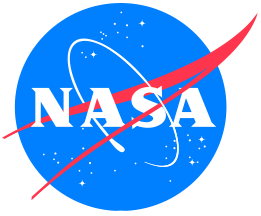
- **Prof. Manos Tentzeris, Georgia Tech**
- **Dr. George E. Ponchak, NASA Glenn**
- **Dr. RongLin Li, Georgia Tech**
- **Dane Thompson, Georgia Tech**
- **Gerald DeJean, Georgia Tech**
- **Guoan Wang, Georgia Tech**
- **Nickolas Kingsley, Georgia Tech**
- **Ramanan Bairavasubramanian, Georgia Tech**



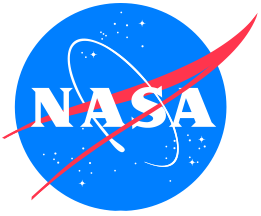
Outline



- **Introduction**
- **Liquid Crystal Polymer (LCP)**
Characterization up to 110 GHz
- **Dual polarized/frequency antenna arrays**
on LCP
- **RF MEMS switches on LCP**
- **Conclusions/Future Work**

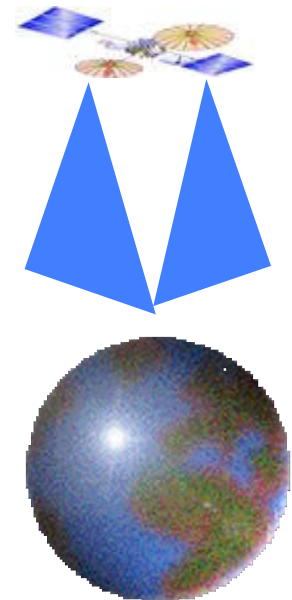


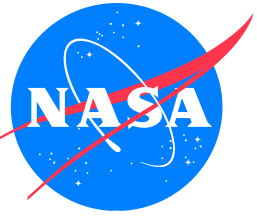
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Applicability to ESE Measurements

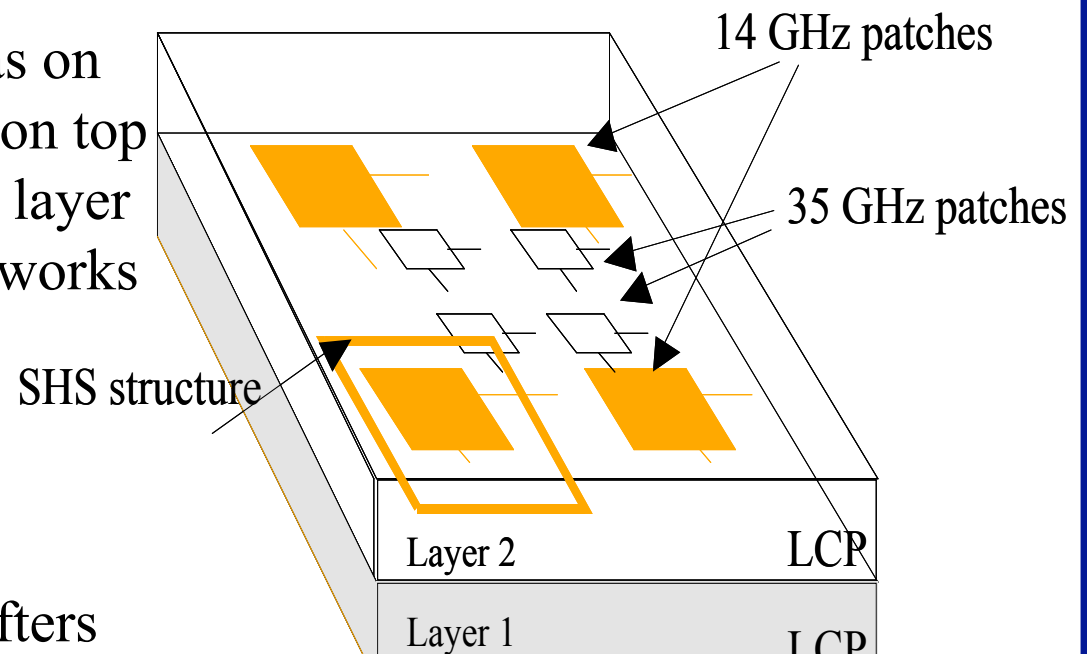
- Accurate monitoring and measurement of the global precipitation, evaporation and cycling of water is required to better understand earth's climate system
- Dual frequency/polarization radiometers are necessary to monitor precipitation patterns
- Antenna and RF front ends that have low cost, low mass, electronic scanning capabilities and are easily deployed, are preferred
- Develop novel dual frequency/polarization array and associated electronics based on System-on-a-Package (SOP) approach

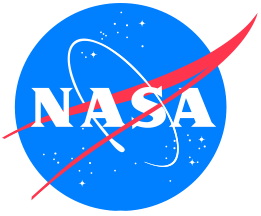




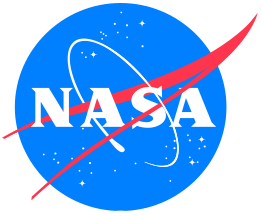
Proposed Technology

- Investigate multi-layer Liquid Crystal Polymer Technology (LCP)
- Two sets of microstrip antennas on different layers: 35 GHz array on top layer, 14 GHz array on bottom layer
- Planar and vertical feeding networks and interconnects
- Implementation of Soft-Hard-Surfaces (SHS) structures for suppression of surface waves
- Usage of RF MEMS phase shifters for electronic scanning



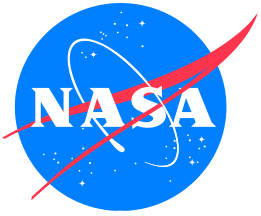


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Why LCP?

- Electrically: $\epsilon_r=2.9$, $\tan \delta=0.002-0.0045$
- Its near hermetic nature suits it as both a mm-wave substrate and package
- Low moisture permeability ($<0.04\%$)
- LCP films from 25 – 200 μm thick can be conveniently laminated for multilayer structures used in system on package (SOP) designs
- Low cost ($\sim \$5/\text{ft}^2$)
- Micromachining ability
- Recyclable
- LCP is flexible, and antennas fabricated on it may be rolled or molded into desired shapes
- Best mix of performance, mechanical integration compatibility, and economic viability



Integration Compatibility



- Transverse coefficient of thermal expansion (CTE) may be engineered to match semiconductors, Cu, and Au

- Two types of LCP with the same electrical properties but different melting temperatures are available. This allows separate “bond” and “core” layers in the lamination process for multi-layer structures
- Low moisture absorption <0.02%

CTE (ppm/ °C)

LCP = 3 - 30 (engr'd)

Cu = 16.8

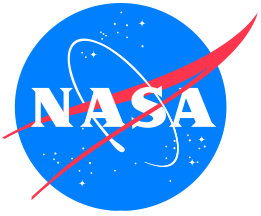
Au = 14.3

Si = 4.2

GaAs = 5.8

SiGe = 3.4 - 5

- **Core**
- TYPE I (335 °C)
- **Bond**
- TYPE II (285 °C)

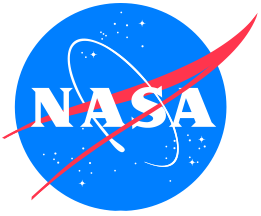


Measurements of Microwave Circuits on LCP



- Dielectric Characterization Structures
 - Ring Resonators
 - Cavity Resonators
 - University of Limoges - France
 - National Institute of Standards and Technology (NIST) - Colorado
- Device Attenuation Characteristics
 - Microstrip
 - CPW, CBCPW

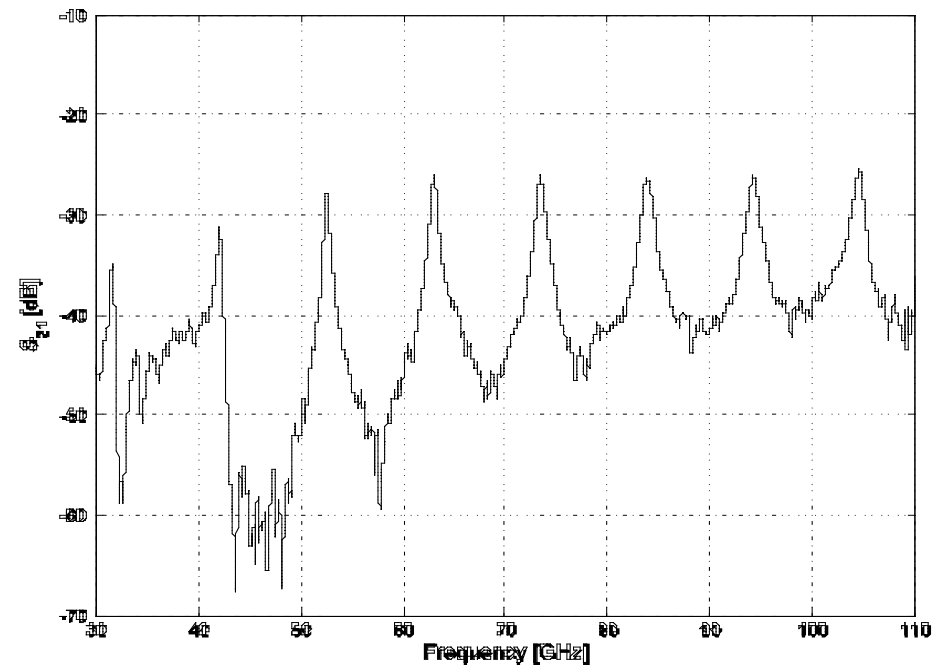
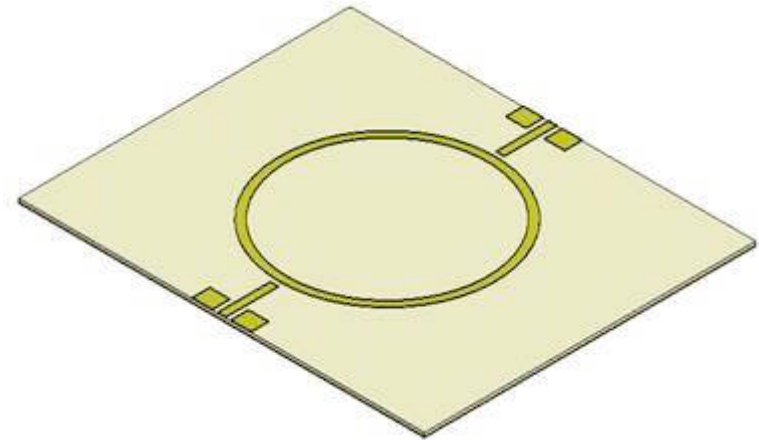


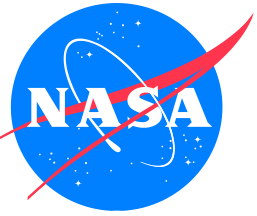


Ring Resonators



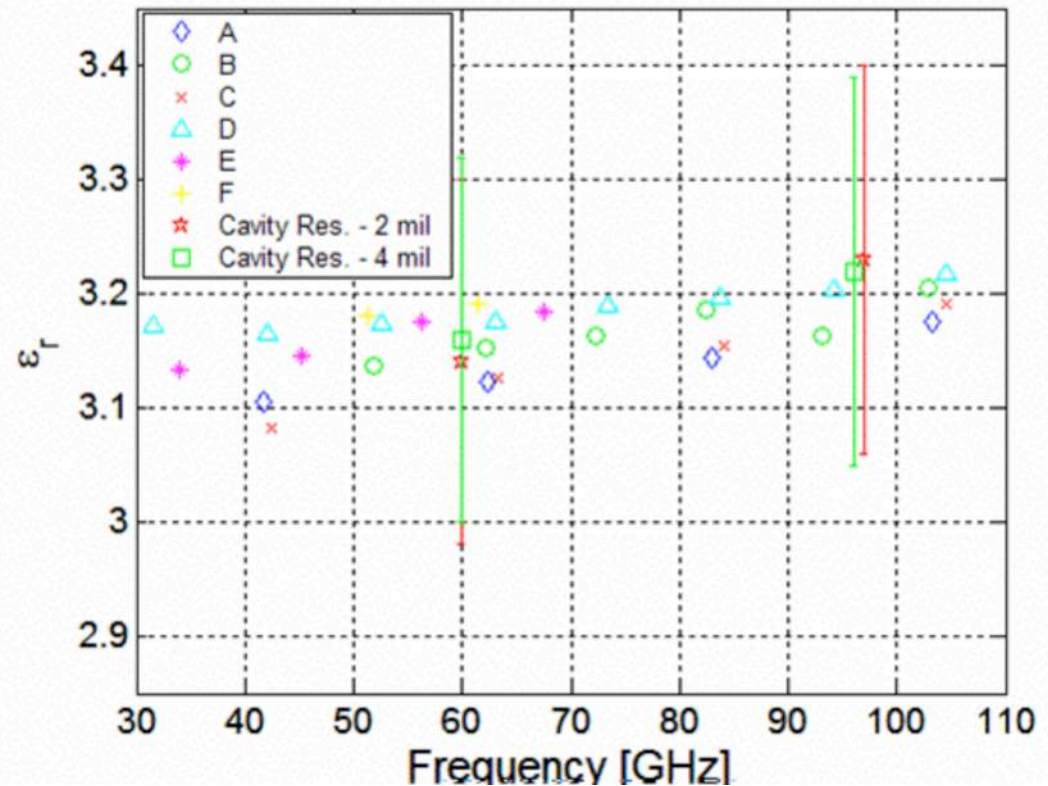
- Several different ring resonator designs were used on different LCP substrate thicknesses in order to extract dielectric properties
- Coaxial connectors are not convenient beyond 50 GHz, so a GSG on-wafer probe was needed in conjunction with a CPW-microstrip transition in order to span 2-110 GHz
- A Thru-Reflect-Line calibration was performed to remove the effects of the transition. This ensures that the ring resonator and microstrip feed are effectively the only parts of the structure being measured.

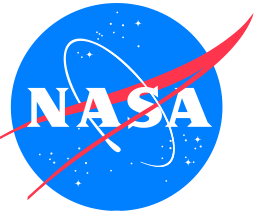




Ring Resonators – LCP ϵ_r Values from 30-105 GHz

- Extracted ϵ_r values for the six ring resonator designs were consistent within 2.6% in any 10 GHz band
- ϵ_r slightly increases with increasing frequency
- Ring resonator and cavity resonator results agree very well

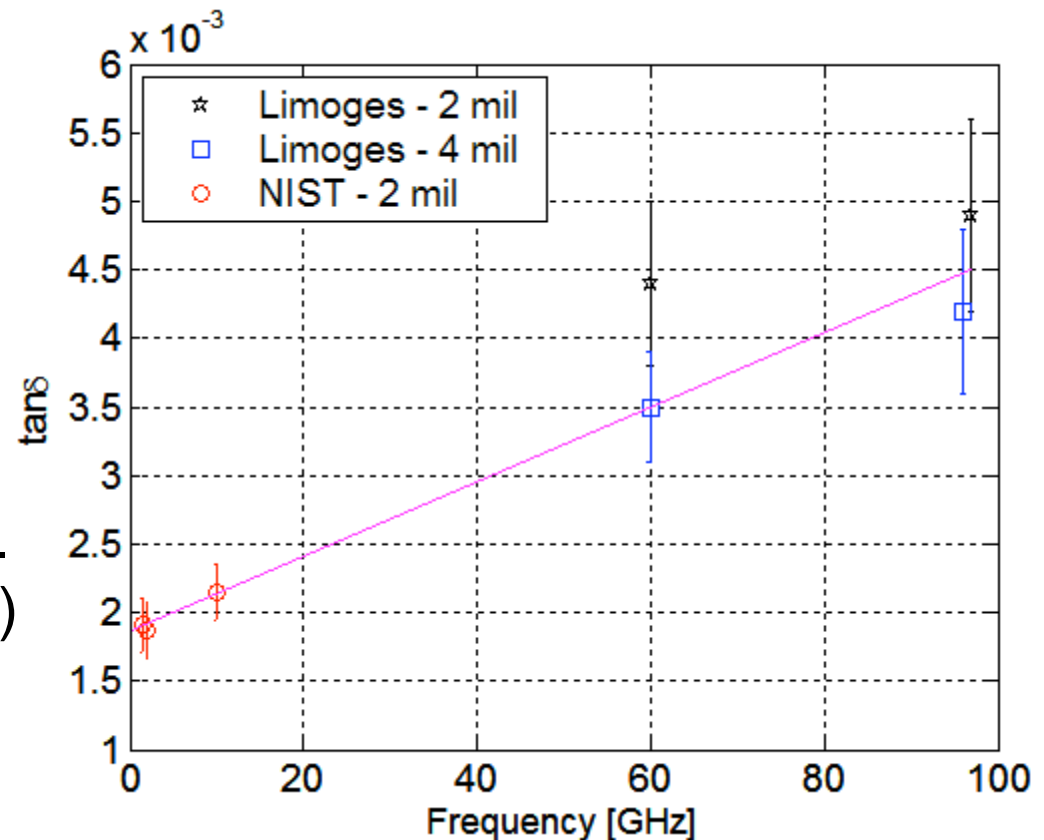




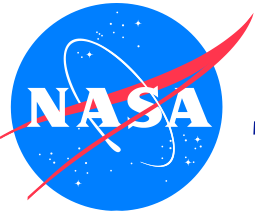
LCP – Loss Data



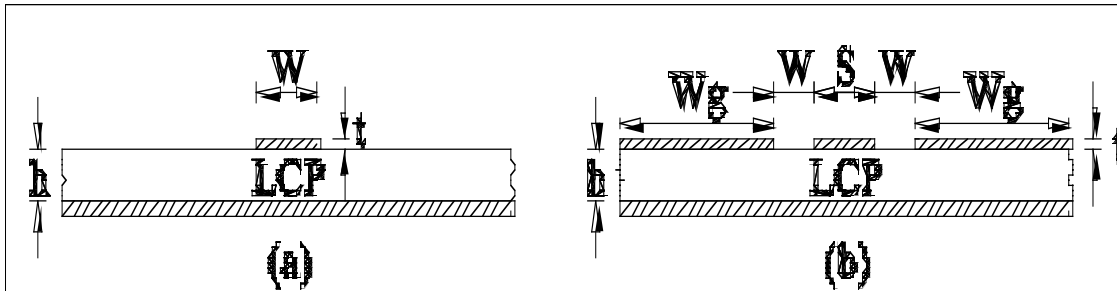
- Results from the resonators show an increasing loss tangent with increasing frequency
- A linear approximation of LCP's loss tangent vs. frequency is shown in (1)



(1)

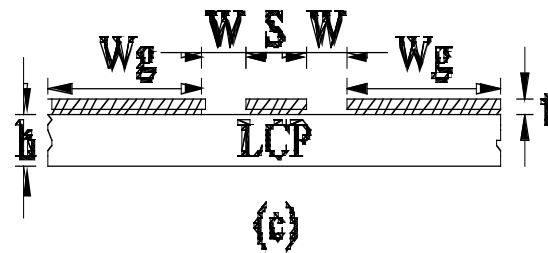


Transmission Line Characterization

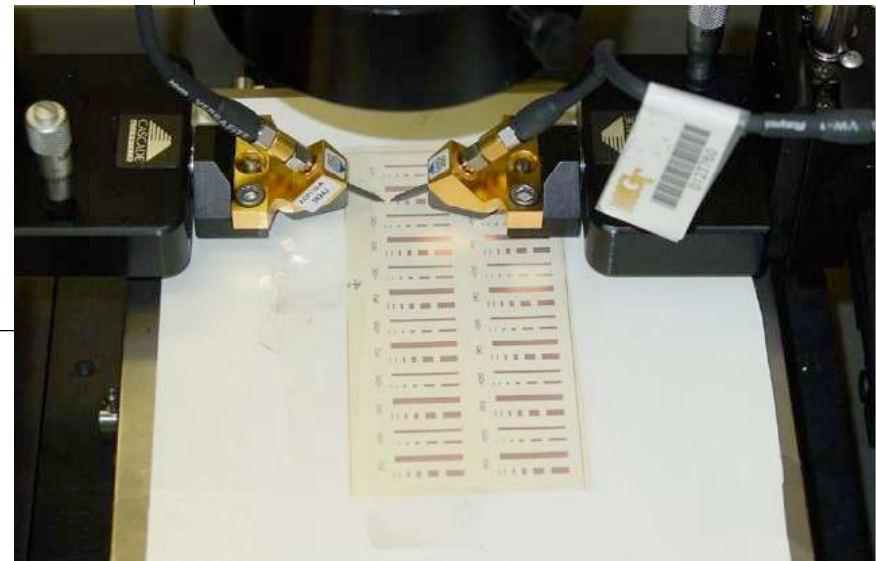


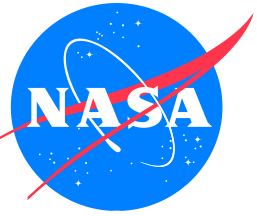
Conductor Backed Coplanar

Microstrip



Coplanar

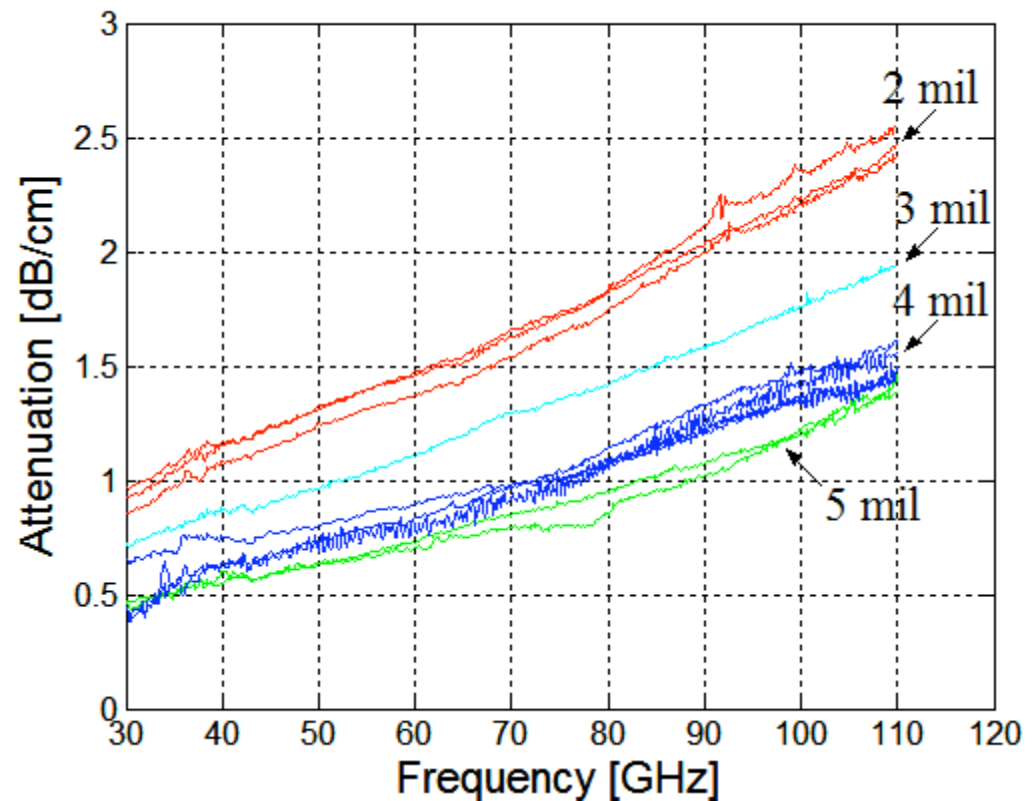




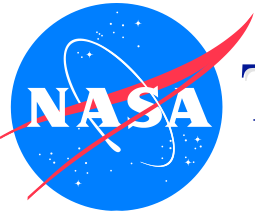
Transmission Line Attenuation: Microstrips



- Microstrip lines were measured with CPW to microstrip transitions
- The transitions were optimized above 30 GHz
- Peak loss ~ 2.5 dB/cm at 110 GHz



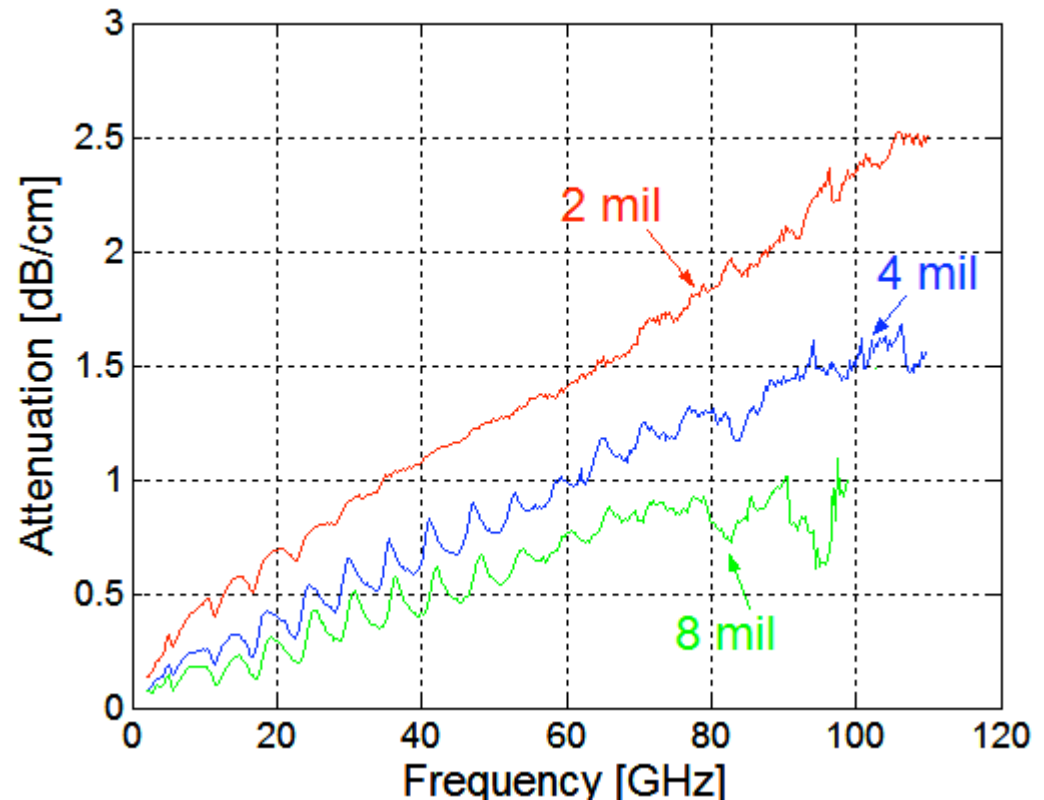
Microstrip attenuation on 2, 3, 4, and 5 mil LCP substrates



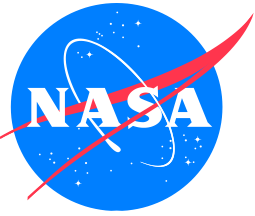
Transmission Line Attenuation: Conductor-backed CPWs



- The 8 mil attenuation plot is truncated beyond ~100 GHz
- Multi-mode propagation in the 8 mil line occurred due to the line geometry
- Peak loss ~2.5dB/cm at 110 GHz



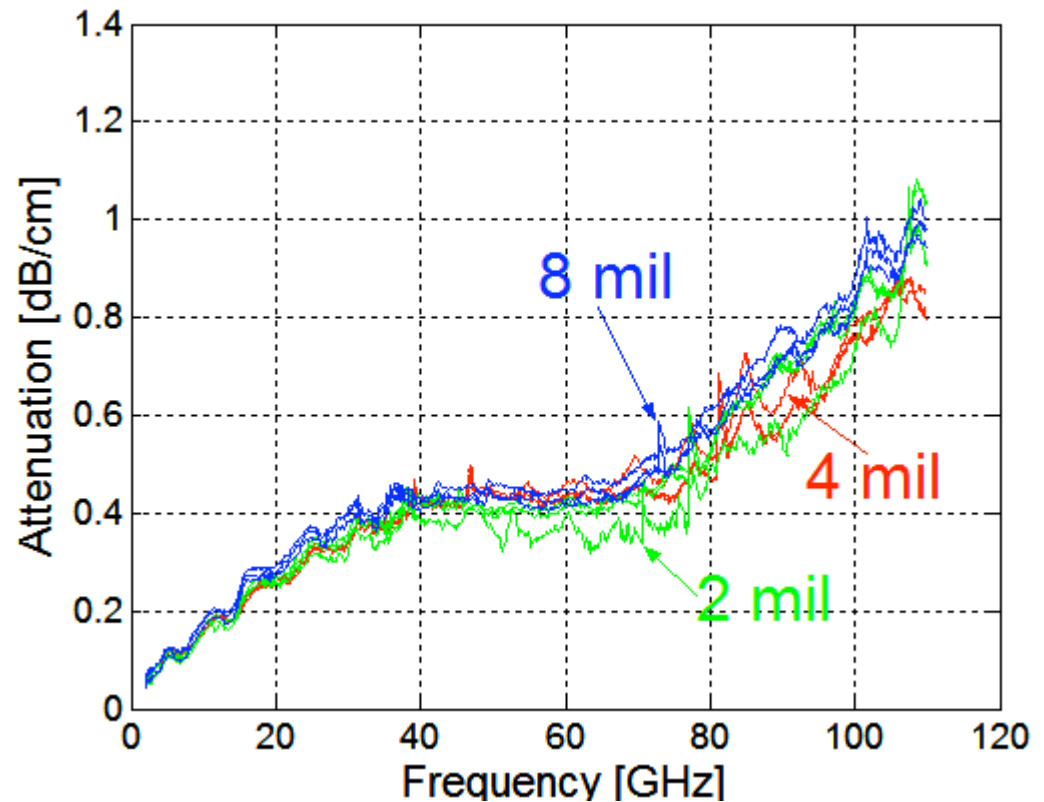
CB-CPW attenuation on 2, 4,
and 8 mil LCP substrates



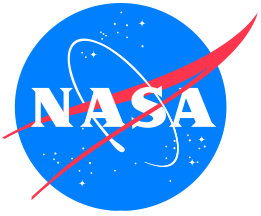
Transmission Line Attenuation: Coplanar Waveguides (CPWs)

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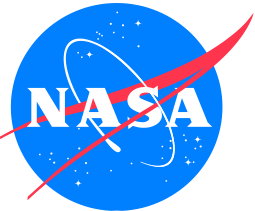
- A low loss foam spacer was used in the measurement to simulate the line suspended in air
- Substrate thickness had little effect on loss results
- All have less than 1 dB/cm loss up to 110 GHz
- A strange flattening of the attenuation was observed between 40-65 GHz and is under investigation



CPW attenuation on 2, 4,
and 8 mil LCP substrates



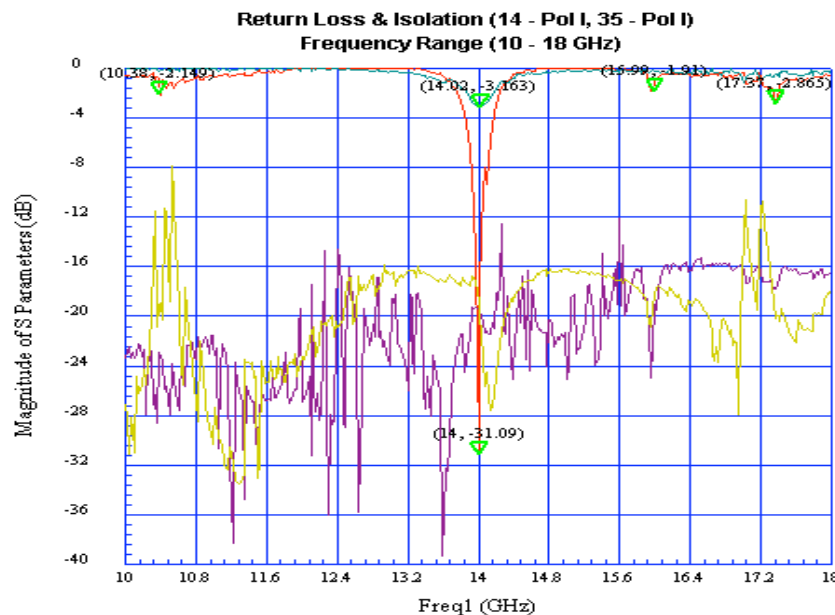
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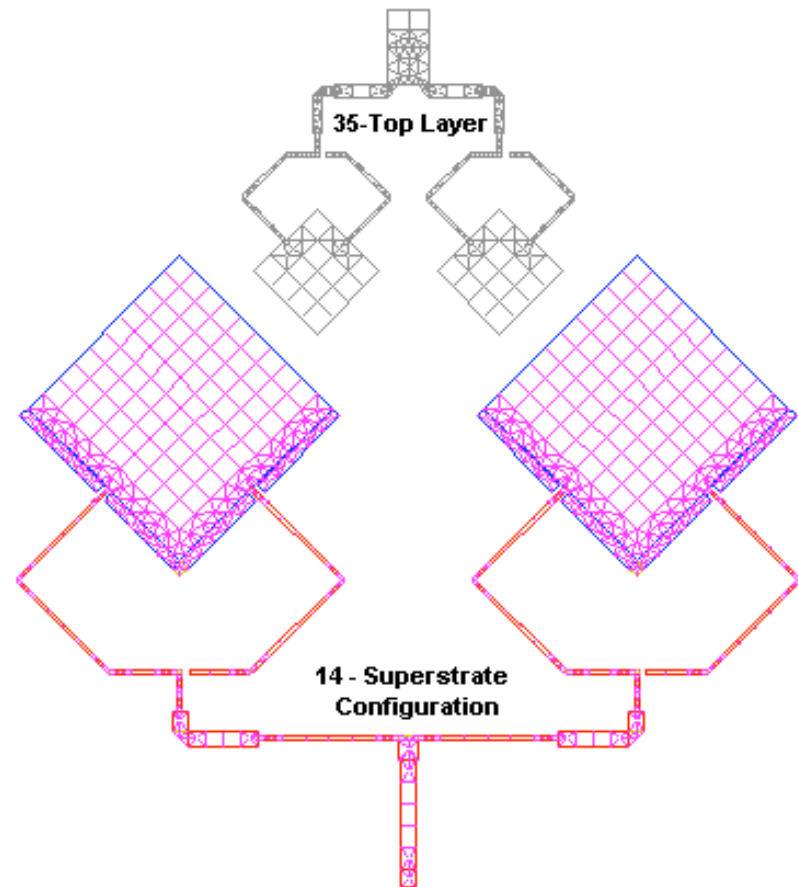
The Entire 14/35 GHz array

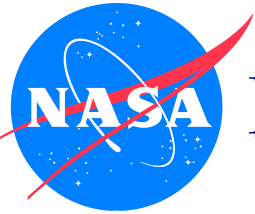


- At 14GHz the array works close to the desired way.
- The coupling between the two layers is low at this frequency.
- There isn't any interference with the “sandwiched” array



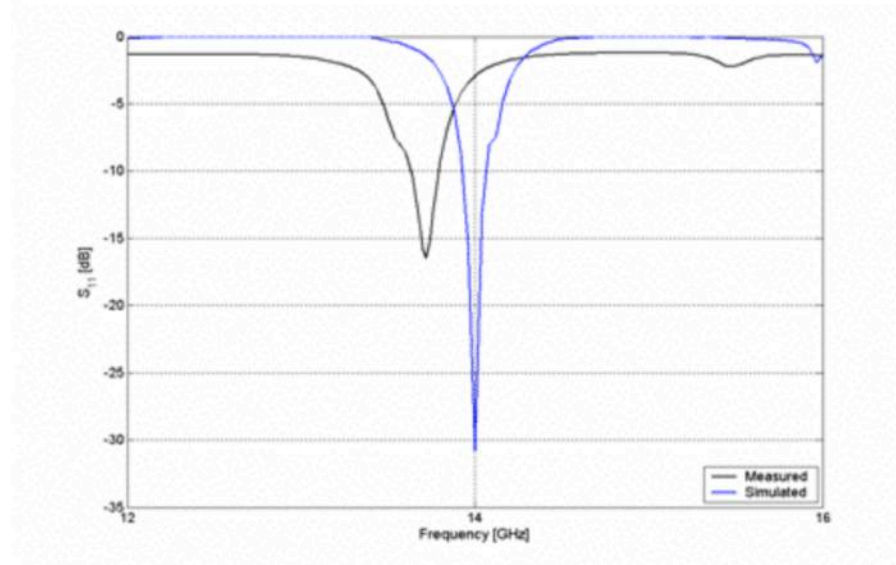
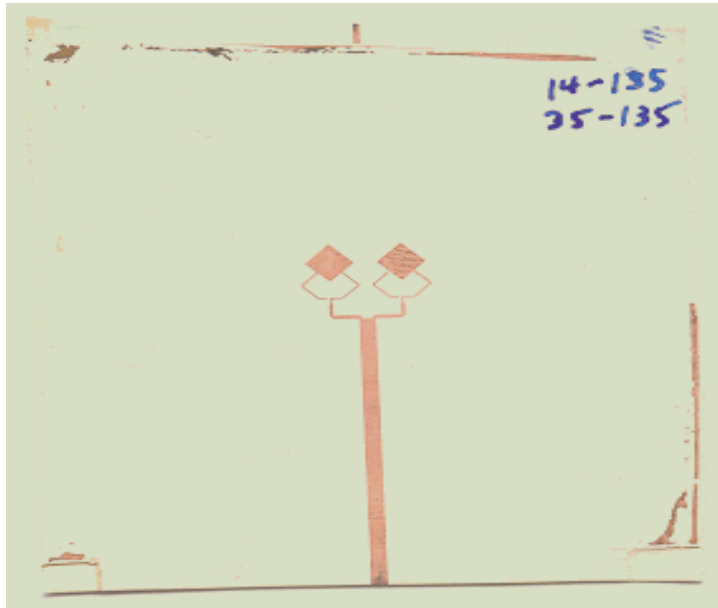
The s-parameter response for 14 GHz excitation.



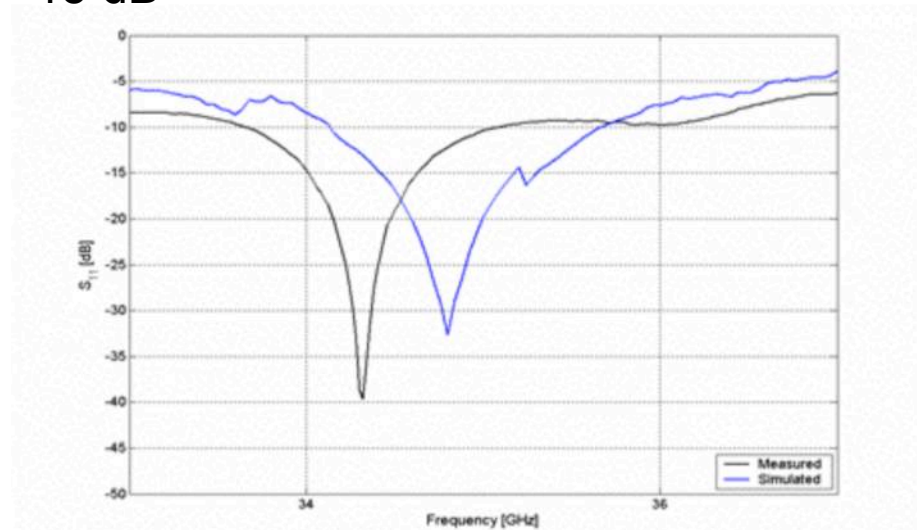


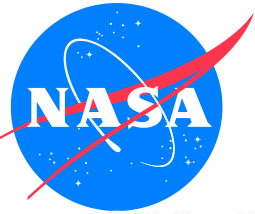
Return Loss of the 14/35 GHz array

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RL > 15 dB

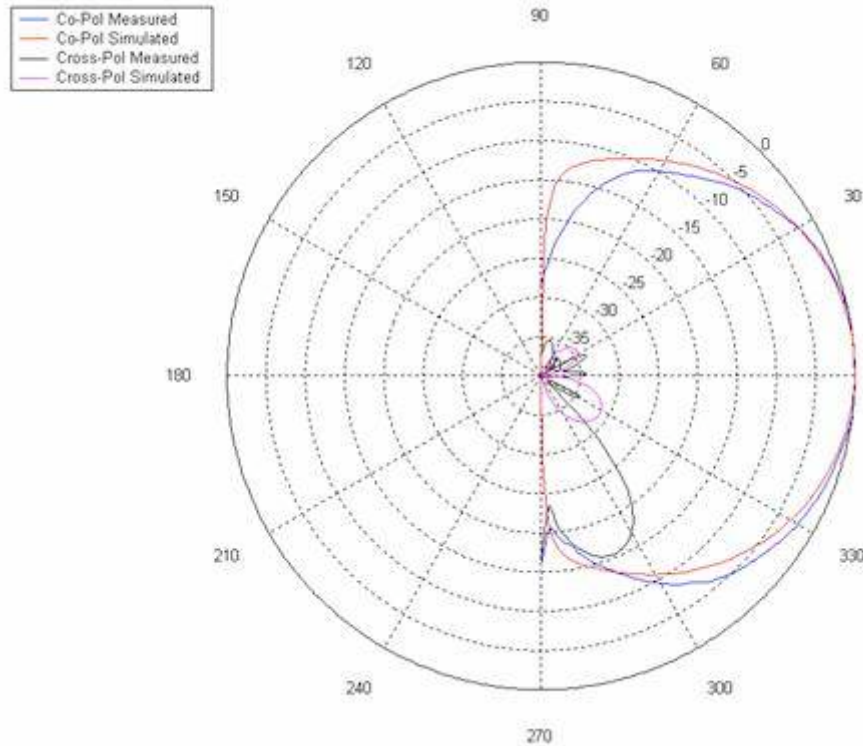




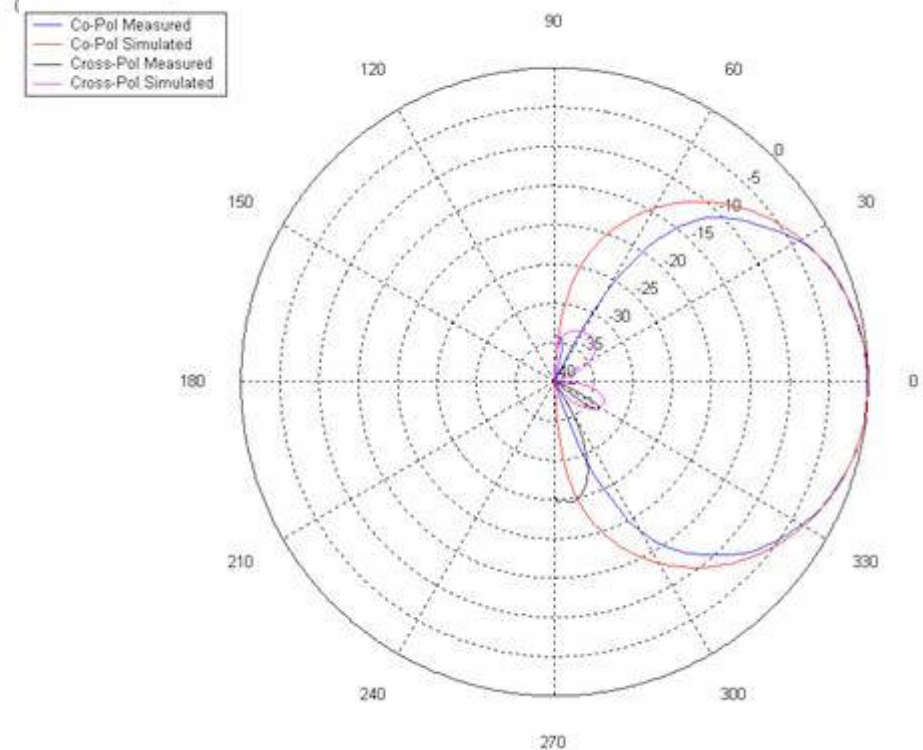
Radiation Patterns at 14 GHz

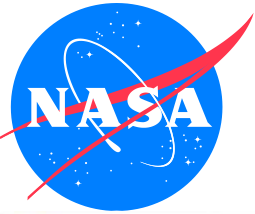


E-plane Radiation Patterns - 14-135-35-135 Excitation at 14GHz

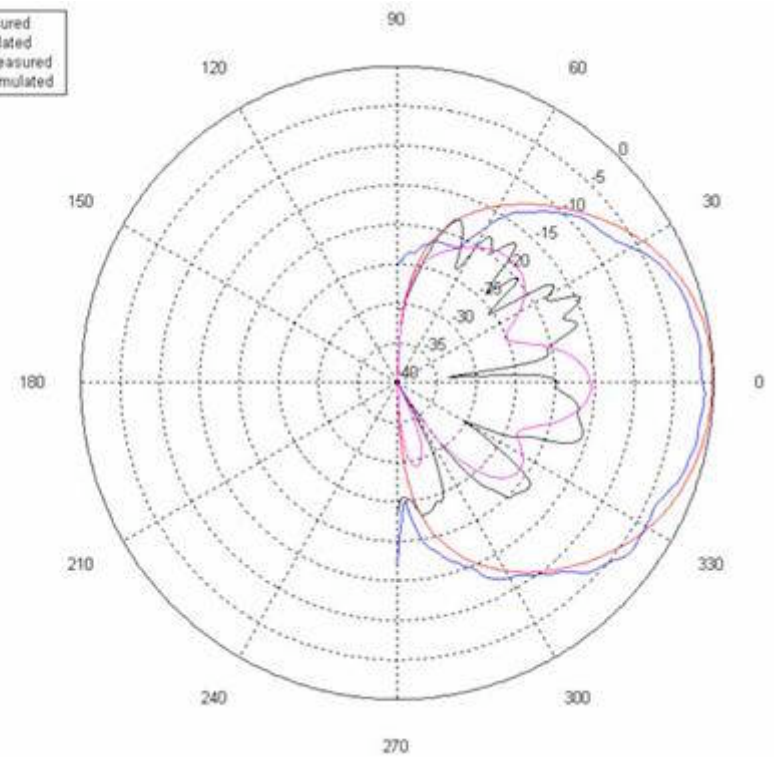
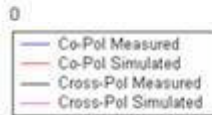
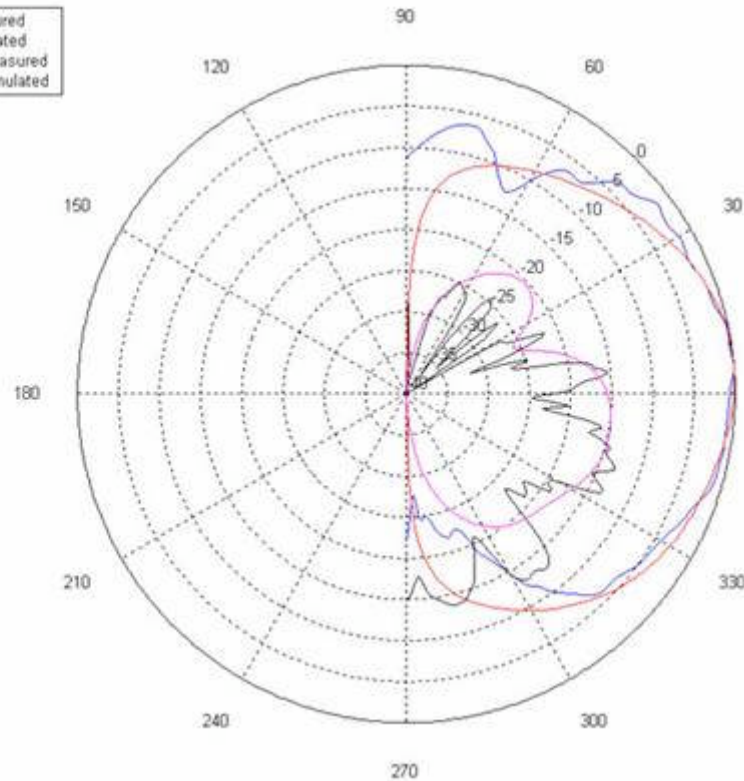
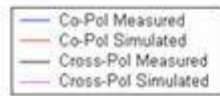


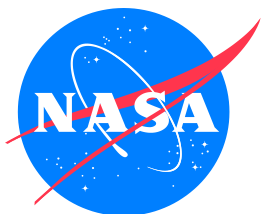
H-plane Radiation Patterns - 14-135-35-135 Excitation at 14GHz





Radiation Patterns at 35 GHz



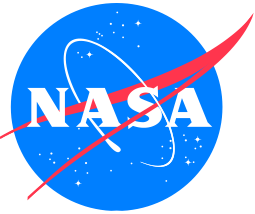


Summary of Results



Characteristic	Simulated 14-135	Measured 14-135
<i>E-Plane -3 dB Beamwidth</i>	65°	67°
<i>H-Plane -3 dB Beamwidth</i>	58°	58°
<i>Max. Cross-pol. Level (E-plane)</i>	-31 dB	-16 dB
<i>Max. Cross-pol. Level (H-plane)</i>	-33 dB	-25 dB

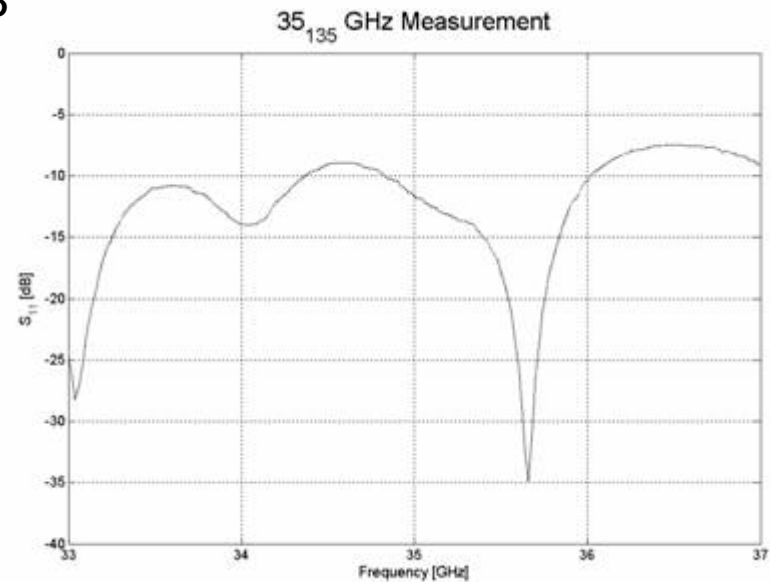
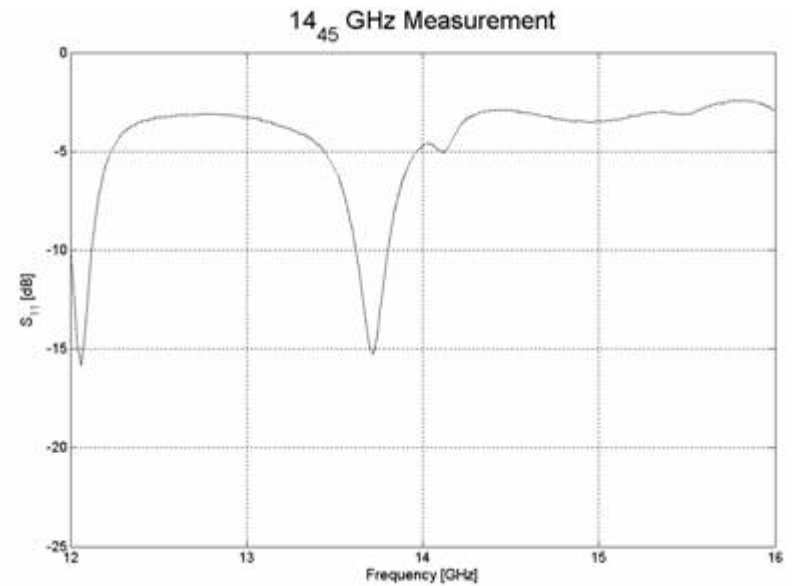
Characteristic	Simulated 35-135	Measured 35-135
<i>E-Plane -3 dB Beamwidth</i>	65°	66°
<i>H-Plane -3 dB Beamwidth</i>	59°	59°
<i>Max. Cross-pol. Level (E-plane)</i>	-15 dB	-13 dB
<i>Max. Cross-pol. Level (H-plane)</i>	-16 dB	-15 dB

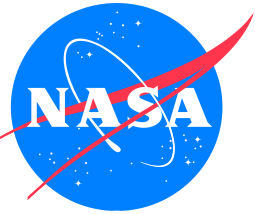


2x2 Array Preliminary Results



RL > 14 dB

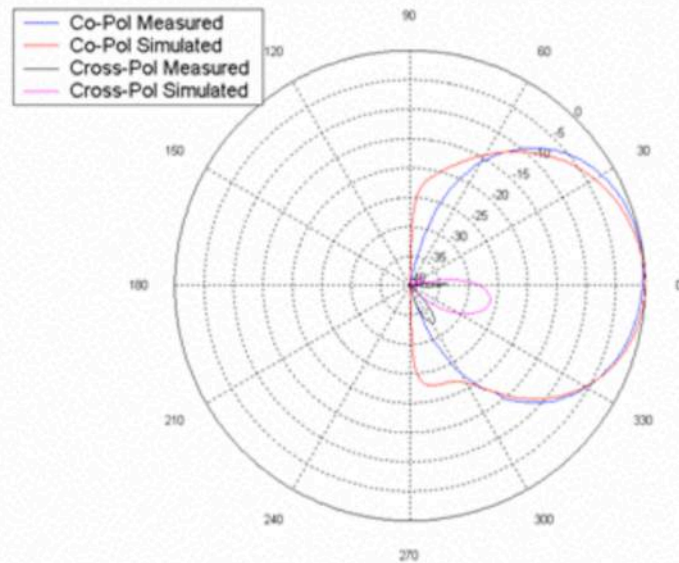




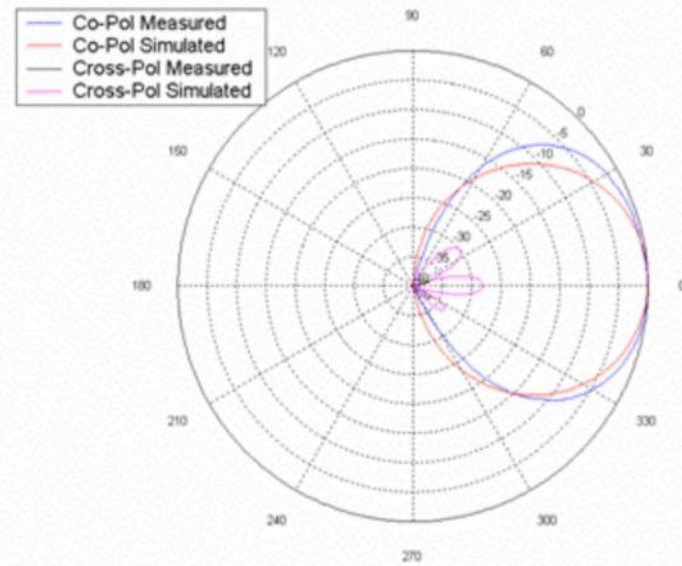
2x2 Array Preliminary Results

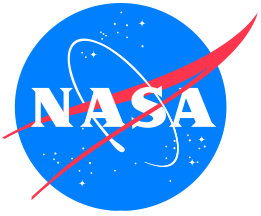


E-plane Radiation Patterns - 14-45

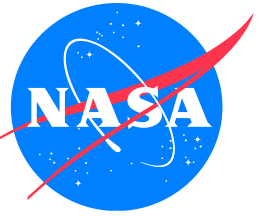


H-plane Radiation Patterns - 14-45

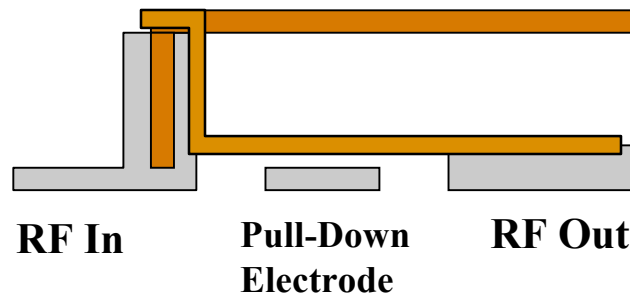




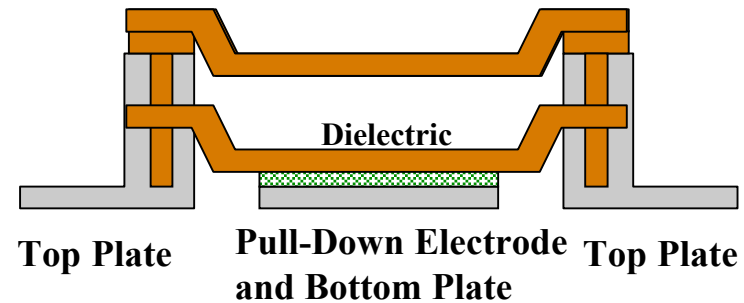
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RF MEMS Switches

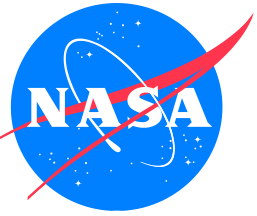


Cantilever beam

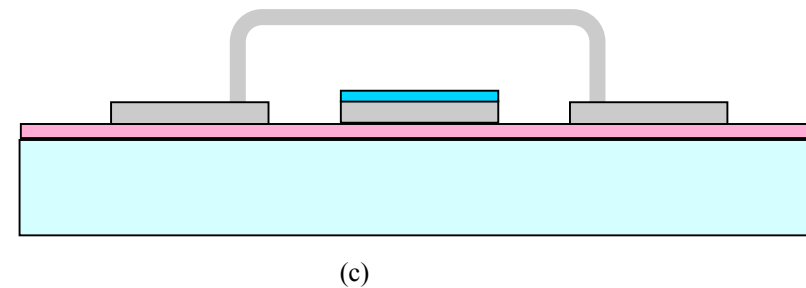
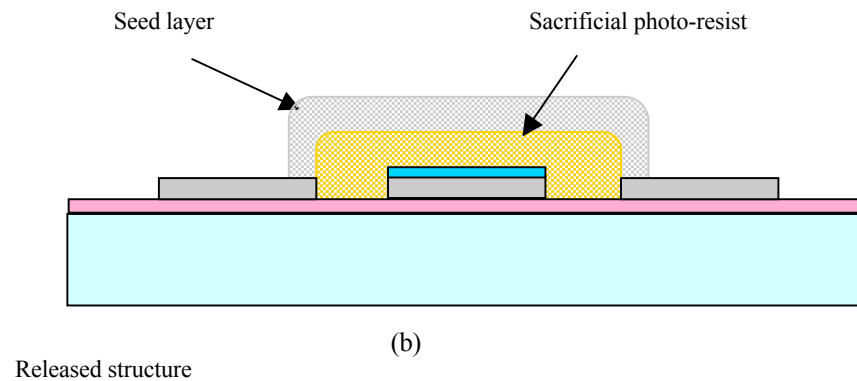
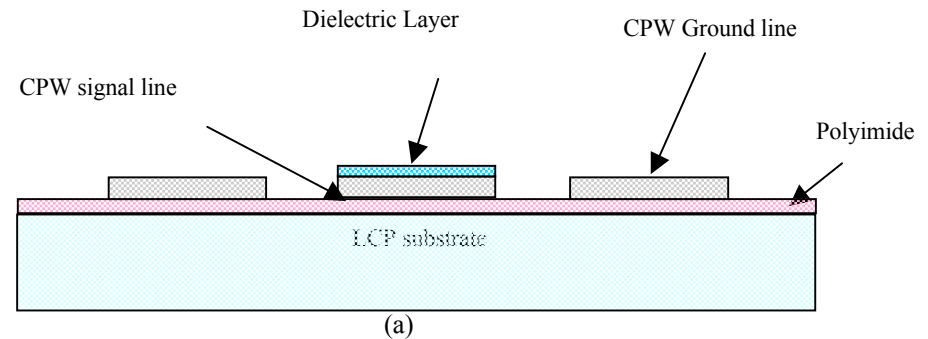
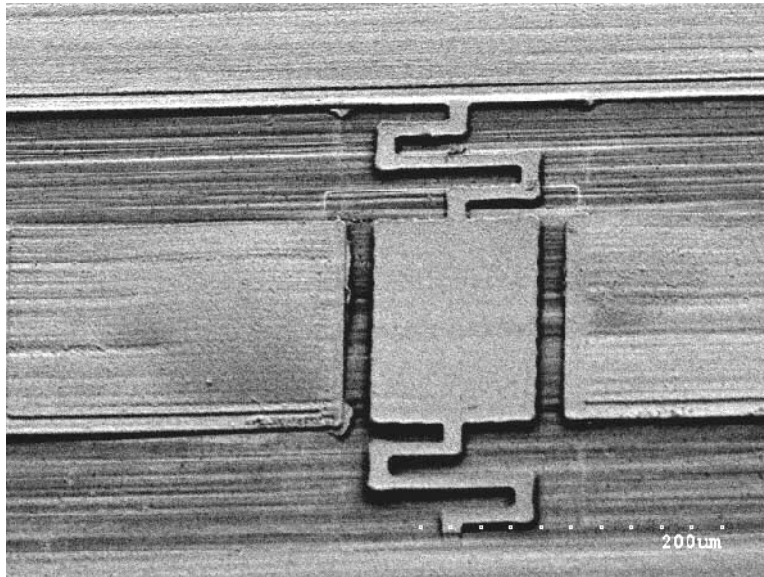


Air-bridge

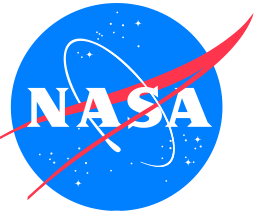
- * Electrostatic actuation (5-60V)
- * Low loss (up to W-band) and low cost
- * High linearity – no distortion ($IIP_3 > 60$ dBm)
- * No power consumption
- * Switching time 1-20 μ s
- * IC fabrication compatible
- * Lifetime > 40 B cycles



RF MEMS Switches on LCP



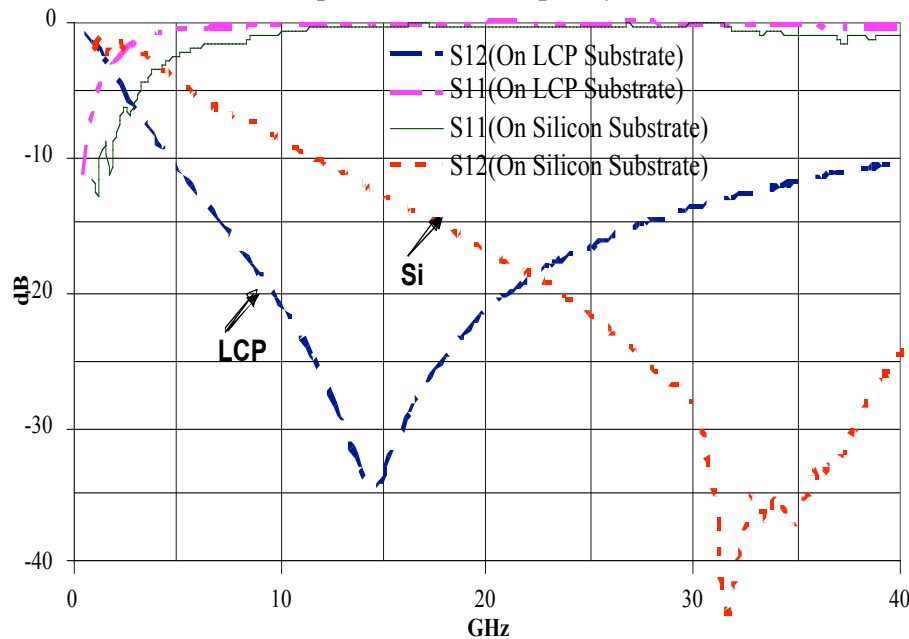
- Air-Gap ~ 1.8 mm
- Actuation voltage ~ 20 -30 V



RF MEMS Switches on LCP

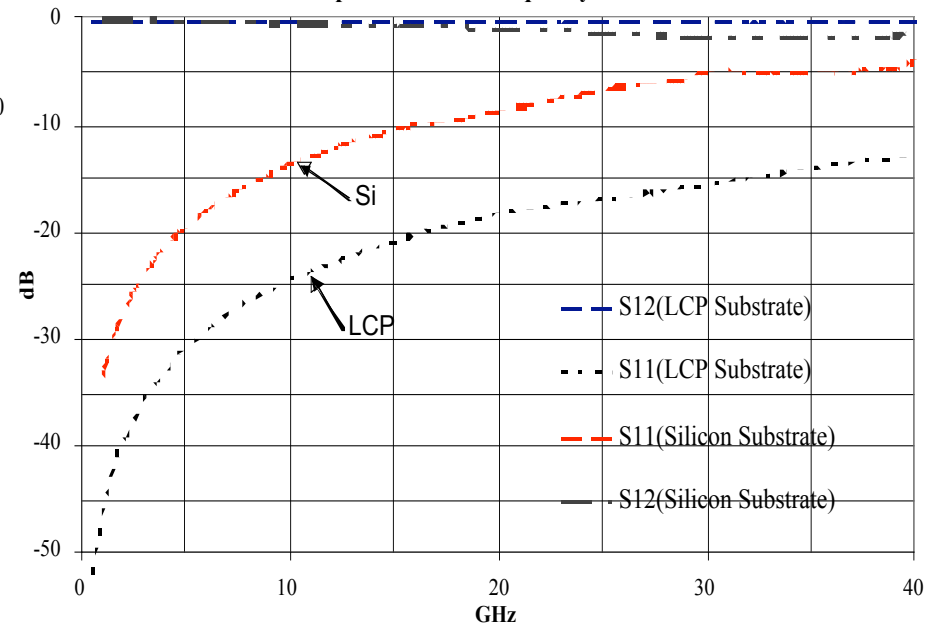


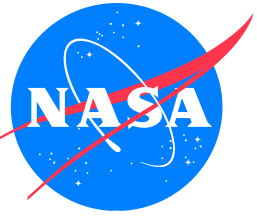
S-parameter vs. Frequency



- For ON state isolation ~ 20 dB at 20 GHz
- For OFF state insertion loss ~ 0.1 - 0.2 dB at 20 GHz
- $C_{ON} \sim 3$ pF (nitride as dielectric layer)
- $C_{OFF} \sim 35$ fF

S-parameter vs. Frequency

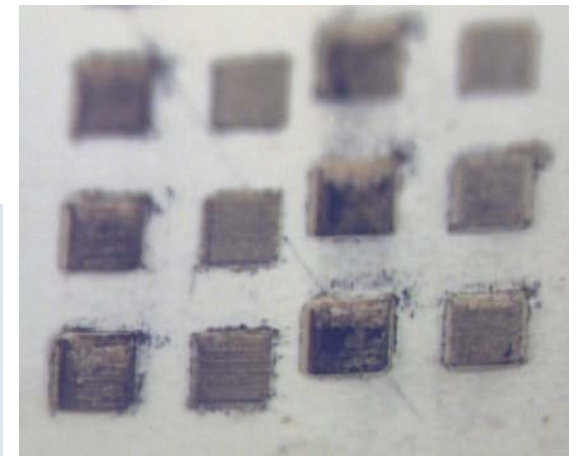
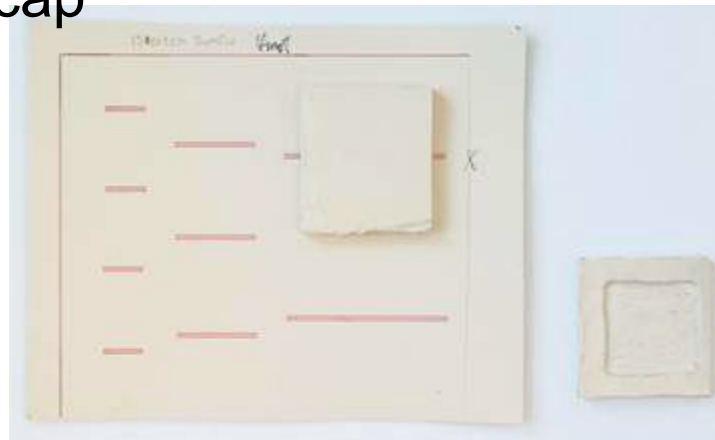
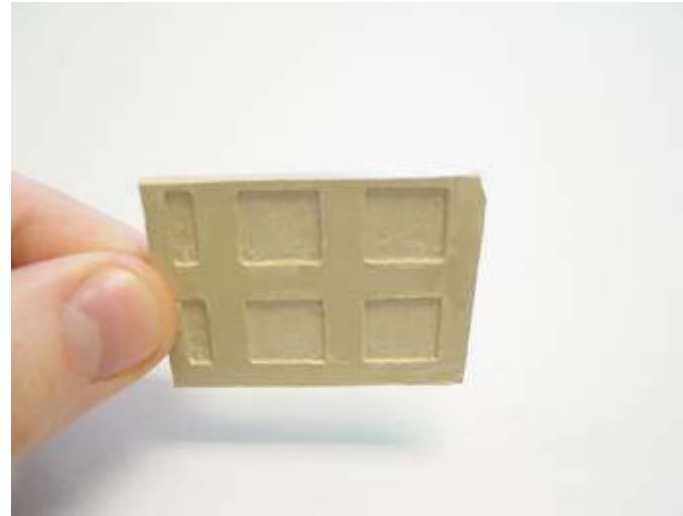


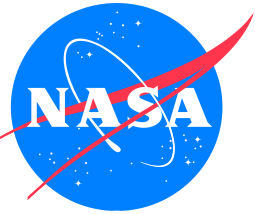


LCP for Integrated Packaging

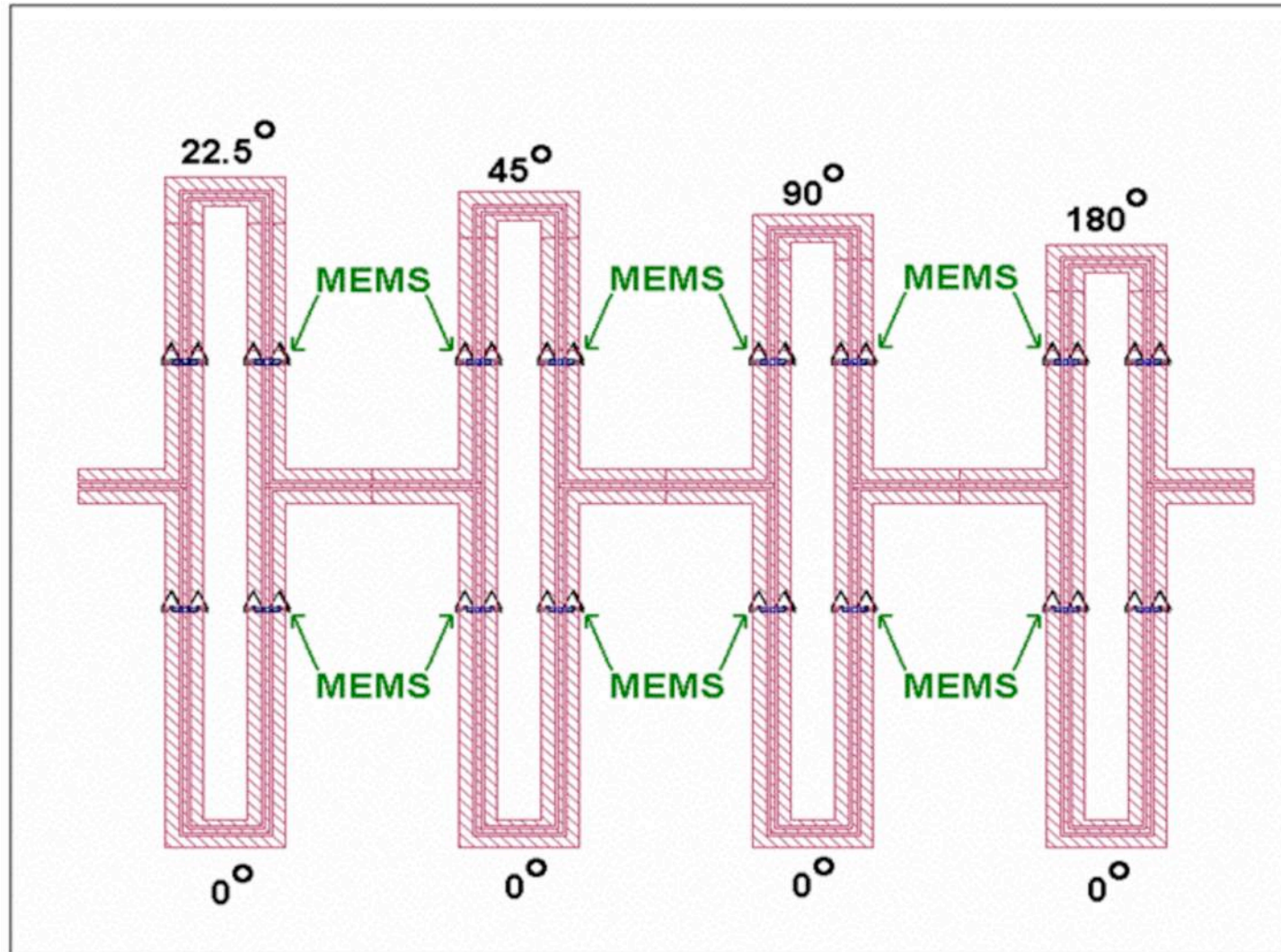


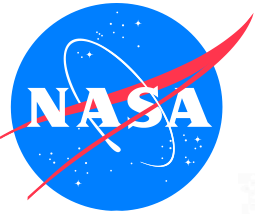
- 19 layers LCP bonded into ~2.3mm thick LCP sheet
- Currently looking to use KrF excimer laser or CO₂ laser to perform micromachining
- Low melting temperature LCP bonding ring to be used around packaging cap perimeter



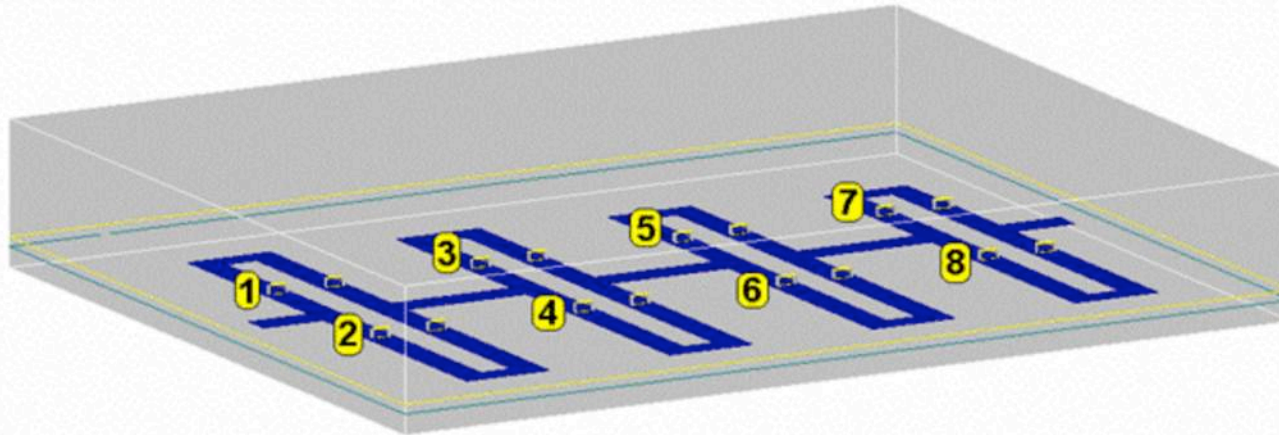


14 GHz 4-bit Phase Shifter on 450 nm Si

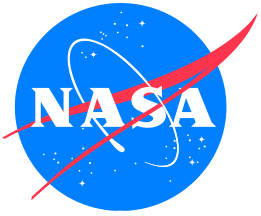




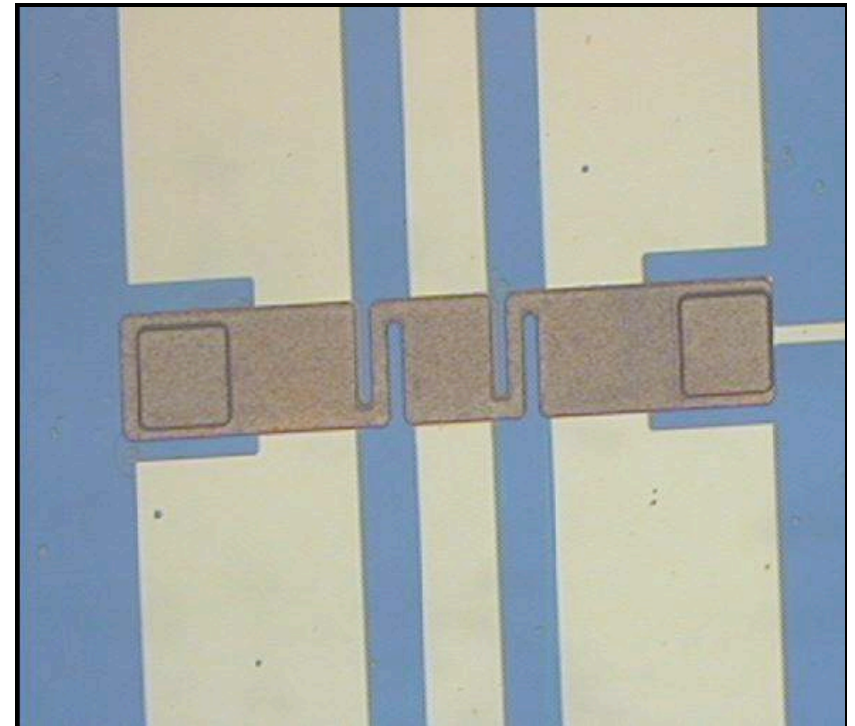
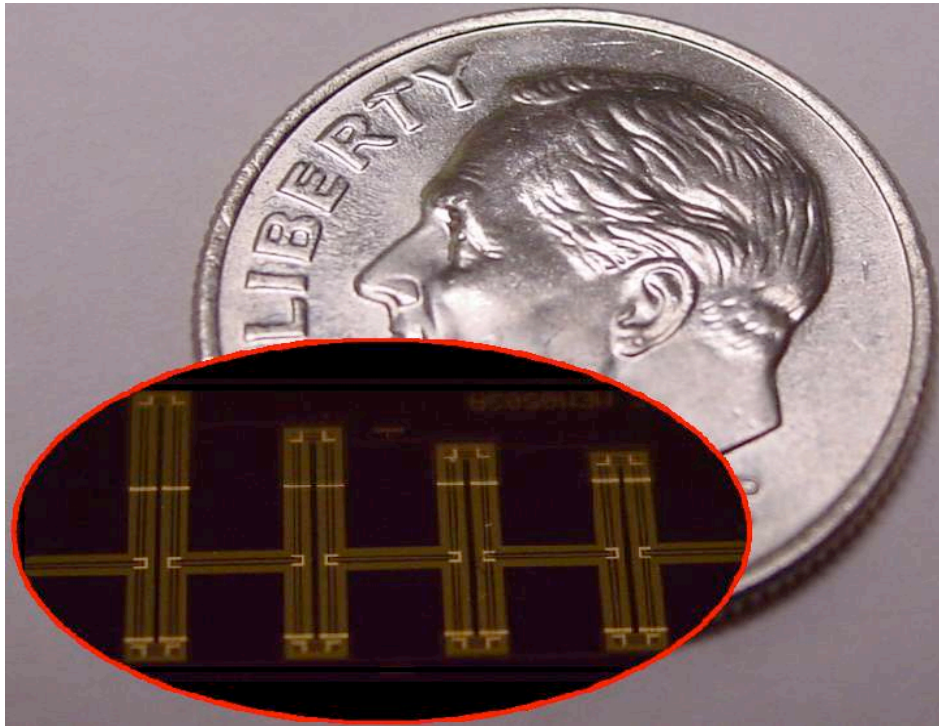
4-bit phase shifter simulated results

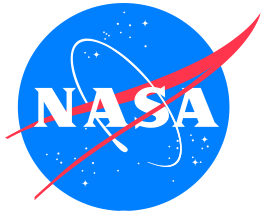


Ideal Phase (degrees)	Actual Phase	Signal Path (MEMS in UP State)	S11 (dB)	S21 (dB)
0	-1.45332	2-4-6-8	-9.761	-0.485
22.5	21.71488	1-4-6-8	-10.341	-0.421
45	44.38869	2-3-6-8	-9.631	-0.501
67.5	67.55689	1-3-6-8	-10.201	-0.436
90	89.22187	2-4-5-8	-7.909	-0.767
112.5	112.39007	1-4-5-8	-8.374	-0.682
135	135.06388	2-3-5-8	-7.803	-0.788
157.5	158.23208	1-3-5-8	-8.262	-0.702
180	178.98201	2-4-6-7	-3.948	-2.239
202.5	202.15021	1-4-6-7	-4.240	-2.053
225	224.82402	2-3-6-7	-3.881	-2.285
247.5	247.99222	1-3-6-7	-4.171	-2.095
270	269.6572	2-4-5-7	-2.951	-3.071
292.5	292.8254	1-4-5-7	-3.210	-2.819
315	315.49921	2-3-5-7	-2.891	-3.133
337.5	338.66741	1-3-5-7	-3.149	-2.876



Fabricated 14 GHz 4-bit Phase Shifters

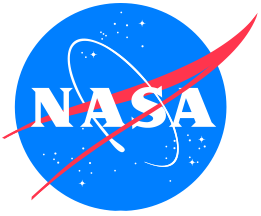




Preliminary measured results



<u>Expected Phase</u>	<u>Phase S21</u>	<u>Phase Error</u>
22.5°	25.697°	3.197°
45°	54.906°	9.906°
90°	95.101°	5.101°
180°	177.88°	2.200°



Conclusions/Future Work



- Loss results of LCP up to 110 GHz confirm viability of material selection
- LCP loss tangent does not exceed 0.005 at 110 GHz.
- 2x1 array designs and return loss/pattern measurements exhibit very good performance
- RF MEMS switches and 2-bit phase shifter exhibit very good performance
- Continue characterization of 2x2 arrays on LCP
- Fabricate and test RF MEMS phase shifters on LCP
- Packaging of the RF MEMS switches using LCP